(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 0 859 425 A1

(12) **EUROPEAN PATENT APPLICATION**
published in accordance with Art. 158(3) EPC

(43) Date of publication:
19.08.1998 Bulletin 1998/34

(21) Application number: **97924365.6**

(22) Date of filing: **10.06.1997**

(51) Int. Cl.⁶: **H01Q 1/42**

(86) International application number:
PCT/JP97/01979

(87) International publication number:
WO 98/10484 (12.03.1998 Gazette 1998/10)

(84) Designated Contracting States:
DE FR GB

(30) Priority: **03.09.1996 JP 233416/96**

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(54) ON-VEHICLE RADAR ANTENNA

(57) Conventional plastic processing technology can be used to manufacture a radome through which electromagnetic waves for radar with high frequencies of several tens of gigahertz can pass with good transmission efficiency, and which amply protects transmitting and receiving antenna elements from wind and rain. The angle of incidence of electromagnetic waves at the surface of the radome is set to be approximately equal to the Brewster angle, said radome being formed from a dielectric material, facing the direction of vehicle travel, and covering the antenna elements which transmit and receive electromagnetic waves. The thickness of the radome where the electromagnetic waves pass through it is set to $0.5 \times n\lambda g$ (where n is a natural number and λg is the guide wavelength of the electromagnetic waves in the dielectric material). A device capable of allowing electromagnetic waves at frequencies of 50 to 100 GHz to pass through it to an ample extent for practical purposes can be formed, and is both small and lightweight. These frequencies are those expected to be allocated to vehicle-mounted radar devices.

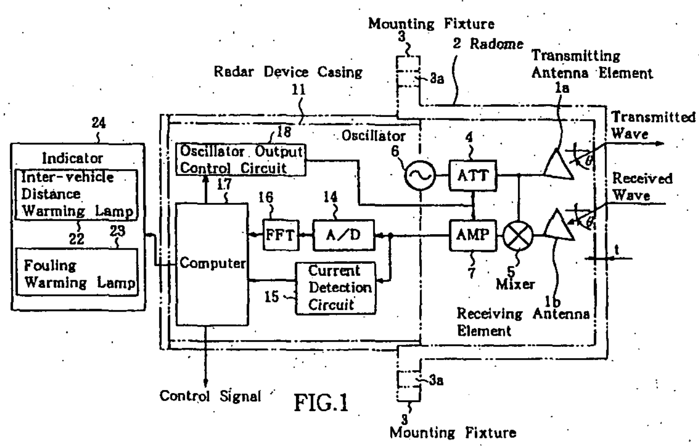

FIG.1

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practical antenna device with a small size construction suitable for mounting on a vehicle.

Disclosure of the Invention

The present invention provides an antenna device wherein the angle of incidence of electromagnetic waves at the surface of the radome covering the antenna element, and the thickness of the radome where the electromagnetic waves pass through it, are specified, thereby enabling the technically optimum electromagnetic wave transmission characteristics to be obtained given the properties of the material comprising the radome.

Namely, according to a first aspect, the present invention is a vehicle-mounted radar antenna fitted to a vehicle and comprising, facing the direction of vehicle travel, an antenna element for transmitting and/or receiving electromagnetic waves, and a radome formed from a dielectric material and covering this antenna element; wherein the angle of incidence (θ) of electromagnetic waves at the surface of the aforesaid radome is preferably set to within $\pm5°$ of the Brewster angle, and more preferably to within $\pm2°$ of the Brewster angle, so that said angle of incidence approximates to the Brewster angle. In this specification, the frequencies of interest as regards transmitted and/or received electromagnetic waves are 50 to 100 GHz (wavelengths of 6 mm to 3 mm). The transmission characteristics of electromagnetic waves with these frequencies rapidly improve as the Brewster angle is approached.

When electromagnetic waves are incident on the surface of a radome covering an antenna element, the transmission characteristics of the radome improve as its reflectivity approaches zero. Maximum transmission efficiency can be obtained for an incident electromagnetic wave if its angle of incidence is set to the Brewster angle, at which reflectivity is close to zero. This Brewster angle differs according to the nature of the dielectric material. For example, if an acrylic resin is used, the Brewster angle will be 58°. A practical plastic molded radome can be obtained if the Brewster angle of the particular dielectric material which it is intended to use is found in advance by separate measurements and the antenna element is set up to give this angle. It is difficult to ensure that the angle of incidence is exactly the Brewster angle and therefore in an actual device the angle of incidence is preferably set to within $\pm5°$ of the Brewster angle and more preferably to within $\pm2°$ of the Brewster angle.

As mentioned above, the frequency of the electromagnetic waves used for vehicle-mounted radar devices is expected to be approximately 60 GHz in Japan and approximately 77 GHz in Europe and America. Consequently, if it is known in advance that electromagnetic waves for radar will be in the range 50 to 100 GHz, it will be possible to cope to a greater or lesser extent with the frequency allocated in any country.

According to a second aspect, the present invention is a vehicle-mounted radar antenna fitted to a vehicle and comprising, facing the direction of vehicle travel, an antenna element for transmitting and/or receiving electromagnetic waves, and a radome formed from a dielectric material and covering this antenna element; wherein the thickness of the aforesaid radome where the electromagnetic waves pass through it is set to:

$$0.5 \times n\lambda g$$

where n is a natural number and λg is the guide wavelength of the electromagnetic waves in the aforesaid dielectric material. The frequency of the transmitted and/or received electromagnetic wave is taken to be 50 to 100 GHz (wavelength of 6 mm to 3 mm).

This second aspect of the invention will now be described in greater detail. A careful study of the transmittance of electromagnetic waves passing through a radome covering an antenna element showed that, taking radome thickness along the horizontal axis and transmittance along the vertical axis, the transmittance characteristic has a general tendency to decrease with increasing thickness, but that it also displays, superimposed on this general trend, a variation with an approximately constant period. An example of the results of measurements of this characteristic is given in FIG. 6. This behavior will be easier to understand if we consider the case where the wavelength of the transmitted electromagnetic wave is comparable with the thickness of the radome, and then analyze the relation between thickness and transmittance as being the result of two factors.

The first factor is energy loss of the transmitted electromagnetic wave in the dielectric material comprising the radome, said energy loss being due to the effect of the imaginary component of the transmittance of that dielectric material. For a specific dielectric material, the energy lost by a transmitted electromagnetic wave is directly proportional to the distance through which the electromagnetic wave passes. In other words, this first factor is the factor which results in the transmittance characteristic having the general tendency to decrease with increasing radome thickness.

The second factor arises from the fact that, because the permittivity of the dielectric material comprising the radome is greater than the permittivity of air, repeated reflections of the electromagnetic wave will occur at the two surfaces of a planar radome. The plurality of reflections occurring at these two surfaces result in electromagnetic waves with identical directions of propagation, which means that interference will occur in accordance with their mutual phase relationships. As a result, considered as a function of radome thickness, the transmittance of an electromagnetic wave will have a sine wave characteristic. Because the wavelength of an electromagnetic wave within a dielectric material

prises, facing the direction of vehicle travel, transmitting antenna element 1a for transmitting electromagnetic waves, receiving antenna element 1b for receiving reflected waves from obstacles, and radome 2 formed from a dielectric material and covering transmitting antenna element 1a and receiving antenna element 1b.

The angle of incidence θ of the transmitted wave and the received wave at the surface of radome 2 is set approximately equal to the Brewster angle, and the thickness t of radome 2 where the electromagnetic waves pass through it is set to:

$$0.5 \times n\lambda g$$

where n is a natural number and λg is the guide wavelength of the electromagnetic wave in the dielectric material. Radome 2 is a box structure formed from a dielectric material. Transmitting antenna element 1a and receiving antenna element 1b are mounted within this box structure, which is provided with fixtures 3 having mounting holes 3a for fitting it to a vehicle body.

Attenuator 4 and mixer 5 are connected to transmitting antenna element 1a, and oscillator 6 is connected to attenuator 4. Mixer 5 is also connected to receiving antenna element 1b, and amplifier 7 is connected to this mixer 5.

Radar device casing 11 is mechanically joined to radome 2 by way of packing 12 and by means of fixing screw 13. Housed within radar device casing 11 is the radar device proper, comprising: A/D converter 14 to which is input the output from amplifier 7, and which performs analogue-to-digital conversion; current detection circuit 15 for detecting the value of the electric current; fast Fourier transform circuit 16 which receives the output of A/D converter 14 and performs a fast Fourier transform on it; computer unit 17 to which is input the outputs of fast Fourier transform circuit 16 and current detection circuit 15, and which calculates the inter-vehicle distance; and oscillator output control circuit 18 which sends a control signal to attenuator 4 and amplifier 7 under control of computer unit 17.

Rear cover 21 is fixed to the rear opening of radar device casing 11 by way of packing 19 and by means of mounting screws 20, whereby the inside of the casing is sealed.

Indicator 24 is disposed at the driver's seat, said indicator comprising inter-vehicle distance warning lamp 22 and fouling warning lamp 23. Indicator 24 lights in response to a warning output from computer unit 17, thereby giving a warning.

As shown in FIG. 3, vehicle-mounted radar device 10 according to a first embodiment of this invention, and constituted as described above, is fixed to bumper 25 using mounting fixtures 3, so as to face the direction of vehicle travel.

The angle of incidence θ of electromagnetic waves at the surface of the radome is set for the dielectric material to be used after the Brewster angle of this dielectric material has been measured in advance. An explanation will now be given of the measurements performed in order to be able to set the angle of incidence θ of the electromagnetic waves. It is a condition of the present invention that the frequencies to be allocated to vehicle-mounted radar devices will be in the range 50 to 100 GHz (wavelengths of 6 mm to 3 mm), but the explanation given in this instance relates to measurements using electromagnetic waves of 60 GHz, which is the frequency expected to be allocated in Japan. FIG. 4 shows the constitution of the main parts of a reflection coefficient measuring device for setting the angle of incidence. The measurements were performed as follows. Namely, acrylic resin test piece 32 serving as the dielectric material was disposed in front of electromagnetic wave absorber 31, electromagnetic waves of 60 GHz generated by transmitter 33 were emitted from transmitting antenna 34 at various angles of elevation θn to this test piece 32, and for each of these angles of elevation θn receiver 36 received the reflected wave via receiving antenna 35. Samples of dielectric material with thickness t of 1.11 mm, 3.03 mm and 5.03 mm were used as test piece 32.

The relation between angle of elevation θn and reflection coefficient R as obtained by measurements is shown in FIG. 5. This shows that whatever the thickness t of the test piece, the reflection coefficient R exhibited a minimum value when the angle of elevation θn was approximately 58°. A minimum value of the reflection coefficient R means that when electromagnetic waves are transmitted at that angle (θn = 58°), the proportion of electromagnetic radiation passing through test piece 32 is greatest. It follows that transmission efficiency can be maximized by setting the angle of incidence θ of the electromagnetic waves shown in FIG. 1 to approximately the Brewster angle characteristic to the material.

The reflection coefficient R can be obtained by means of the following formula.

$$R = \frac{1-\exp(-j^2\delta)}{1-R_p'^2 \exp(-j^2\delta}$$

$$\delta = \frac{2\pi t}{\lambda}\sqrt{\varepsilon_r - \sin^2\theta}$$

$$R'_p = \frac{n^2\sqrt{1-\sin^2\theta}-\sqrt{n^2-\sin^2\theta}}{n^2\sqrt{1-\sin^2\theta}+\sqrt{n^2-\sin^2\theta}}$$

k_0 : coefficient
n : refractive index n_r-jn_i
n_r : real part of refractive index
n_i : imaginary part of refractive index.

FIG. 6 shows the relation between thickness t of dielectric material and transmittance T of an electromagnetic wave of frequency 60 GHz. This relation is shown for acrylic resin, polycarbonate resin, ABS resin and Teflon resin. These results show that transmittance does not decrease in direct proportion to an increase in thickness. For example, in the case of acrylic resin, although transmittance at a thickness of 2.3 mm is 87%, at a thickness of 3.1 mm the transmittance rises to 95%. It decreases to 85.5% at 3.9 mm but rises again to 93% at 4.6 mm.

This characteristic can be utilized both to satisfy the mechanical strength requirement and to select a thickness t at which a high transmittance T will be obtained. For example, when acrylic resin is used, setting thickness t to 4.6 mm enables a transmittance T of 93% to be obtained.

For a qualitative explanation of the characteristic exemplified in FIG. 6, please refer to the detailed explanation which was given above in "Disclosure of the Invention".

As has been explained above, the present invention enables conventional plastic processing technology to be used to manufacture a radome through which electromagnetic waves for radar with high frequencies of several tens of gigahertz can pass, and which amply protects an antenna element from wind and rain. The present invention also enables a practical device with a small size construction to be implemented inexpensively.

Second Embodiment

FIG. 7 is a perspective view showing the external appearance of a vehicle-mounted radar antenna according to a second embodiment of this invention.

A vehicle-mounted antenna element according to a second embodiment of the present invention comprises the antenna element and radar device proper pertaining to the first embodiment and illustrated in FIG. 1. The antenna element comprises transmitting antenna element 1a, receiving antenna element 1b, attenuator 4, mixer 5, oscillator 6 and amplifier 7. The radar device proper comprises A/D converter 14, current detection circuit 15, fast Fourier transform circuit 16, computer unit 17 and oscillator output control circuit 18. However, in this second embodiment, the antenna element and the radar device proper are both housed within casing 40 which has been molded as a single box structure. Fixtures 41 having mounting holes 41a are formed on casing 40, and rear cover 21 is fixed to the rear of casing 40 by way of packing 19 and by means of mounting screws 20.

The angle of incidence θ of the electromagnetic waves at the radome surface, and the thickness t of the radome portion, of a vehicle-mounted radar antenna according to this second embodiment of the invention thus constituted are set in the same manner as in the first embodiment.

This second embodiment gives the same effect as the first embodiment and has the advantage that because all components are housed in one casing, the number of parts is reduced.

Claims

1. A vehicle-mounted radar antenna fitted to a vehicle and comprising, facing the direction of vehicle travel, an antenna element for transmitting and/or receiving electromagnetic waves, and a radome formed from a dielectric material and covering this antenna element;
   wherein the angle of incidence (θ) of electromagnetic waves at the surface of the aforesaid radome is set to within ±5° of the Brewster angle.

2. A vehicle-mounted radar antenna according to claim 1, wherein the frequency of the electromagnetic waves is 50 to 100 GHz (wavelength of 6 mm to 3 mm).

3. A vehicle-mounted radar antenna fitted to a vehicle and comprising, facing the direction of vehicle travel, an antenna element for transmitting and/or receiving electromagnetic waves, and a radome formed from a dielectric material and covering this antenna element;
   wherein the thickness of the aforesaid radome where the electromagnetic waves pass through it is set to:

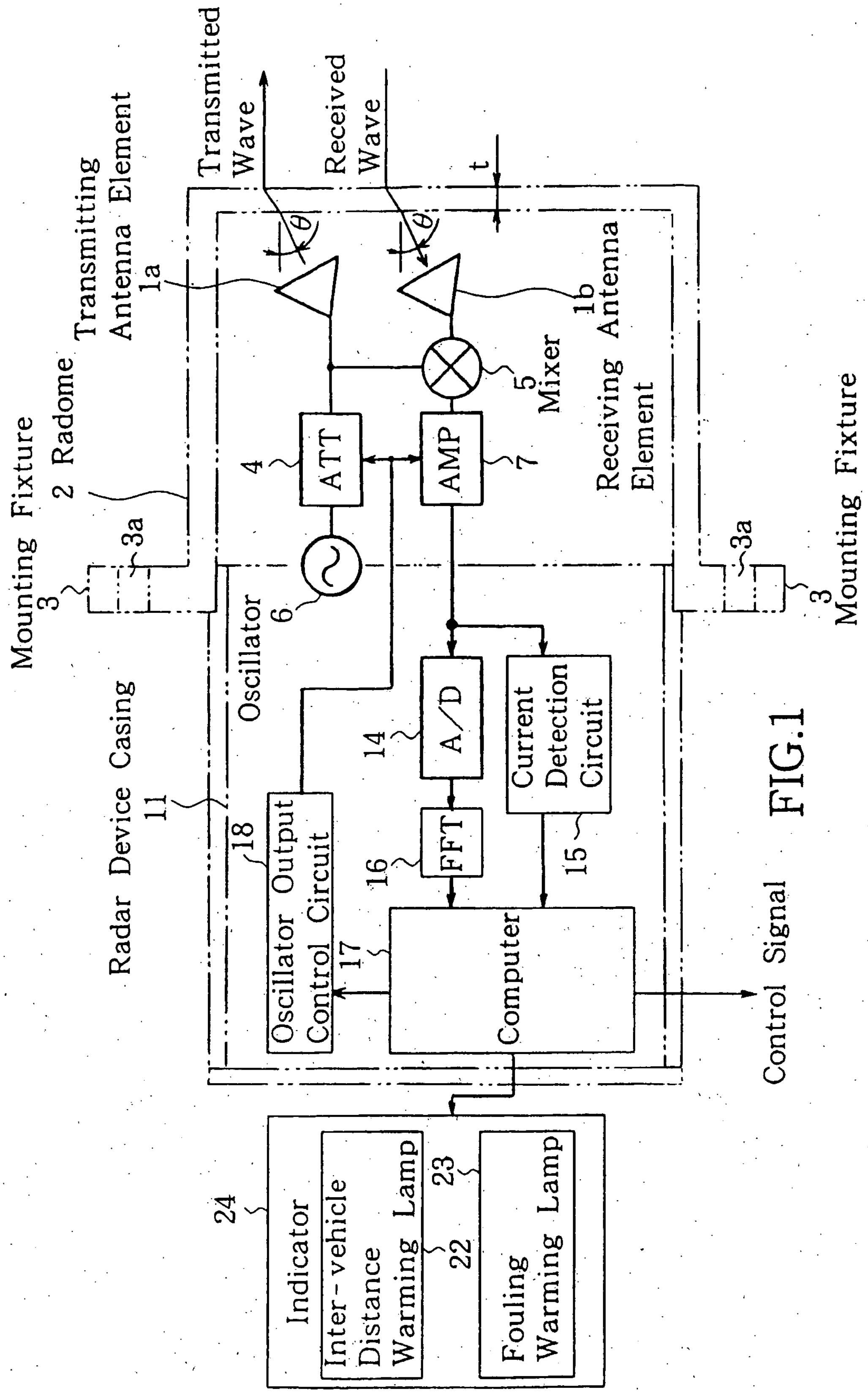
Transmitted Wave
Received Wave
Transmitting Antenna Element
1a
θ
θ
t
1b
Receiving Antenna Element
Mounting Fixture
2 Radome
3
3a
4
ATT
AMP
7
5
Mixer
Receiving Element
3a
3
Mounting Fixture
6
Oscillator
Radar Device Casing
11
14
A/D
Current Detection Circuit
15
18
Oscillator Output Control Circuit
16
FFT
17
Computer
Control Signal
24
Indicator
Inter-vehicle Distance Warming Lamp
22
23
Fouling Warming Lamp

FIG.1

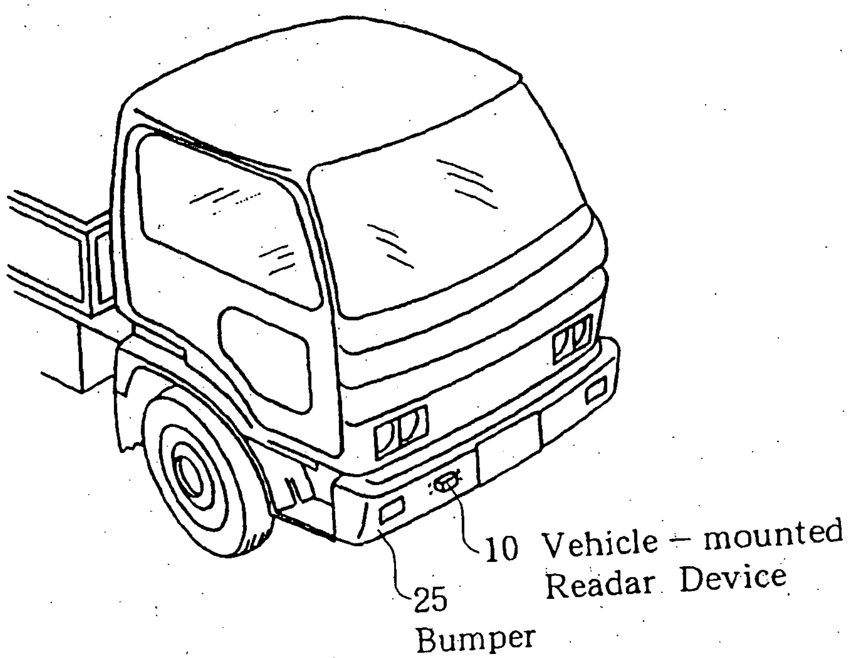

FIG.3

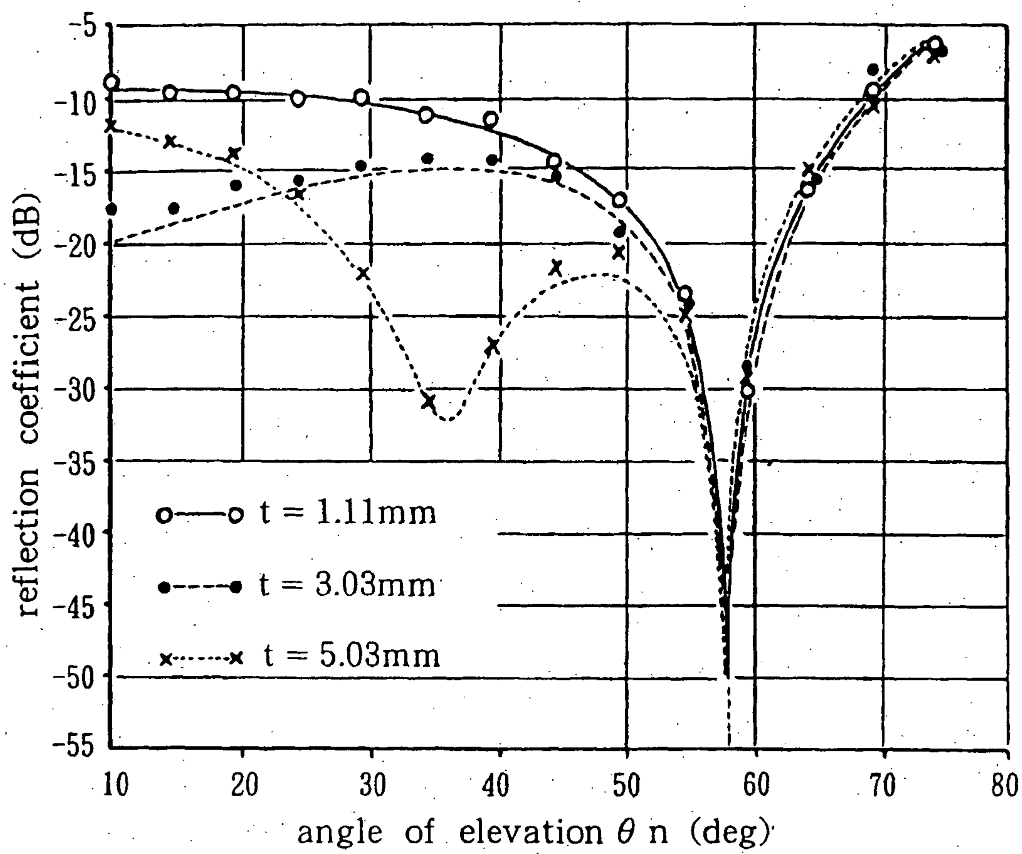
-5
-10
-15
-20
-25
-30
-35
-40
-45
-50
-55
reflection coefficient (dB)
10
20
30
40
50
60
70
80
angle of elevation θ n (deg)
t = 1.11mm
t = 3.03mm
t = 5.03mm

FIG.5

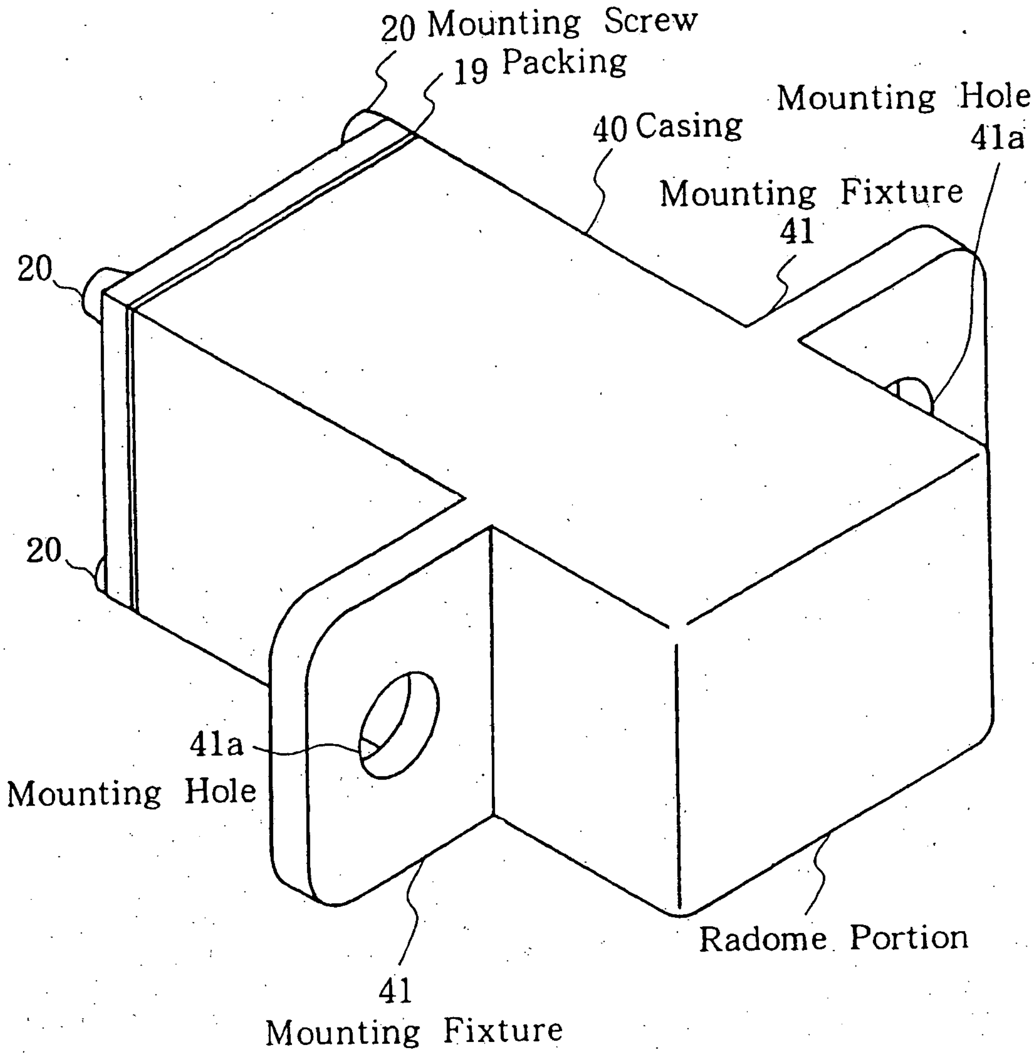
20 Mounting Screw
19 Packing
40 Casing
Mounting Hole
41a
Mounting Fixture
41
20
20
41a
Mounting Hole
41
Mounting Fixture
Radome Portion

FIG.7

INTERNATIONAL SEARCH REPORT

International application No. PCT/JP97/01979

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
	right column, lines 13 to 15 (Family: none)	
Y	JP, 7-81490, A (Hino Motors, Ltd.), March 28, 1995 (28. 03. 95), Page 3, left column, line 27 to right column, line 21 (Family: none)	1 - 7
Y	JP, 50-103234, A (Sumitomo Electric Industries, Ltd.), August 15, 1975 (15. 08. 75), Page 2, upper left column, lines 5 to 15 (Family: none)	1 - 2
Y	JP, 49-46662, A (Sumitomo Electric Industries, Ltd.), May 4, 1974 (04. 05. 74), Page 4, upper left column, line 6 to upper right column, line 3 (Family: none)	1 - 2

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